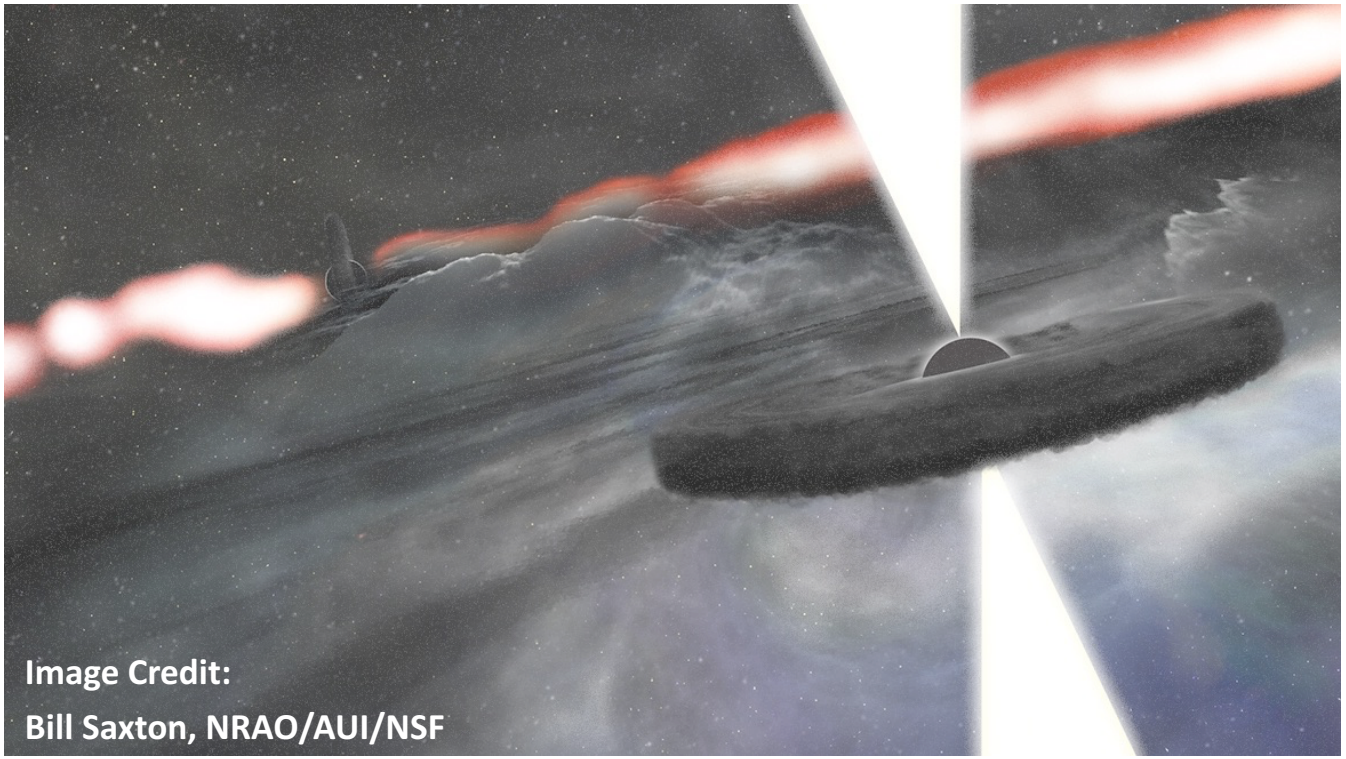
Revolutionizing AGN Science with the ngVLA



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ngVLA Science Workshop

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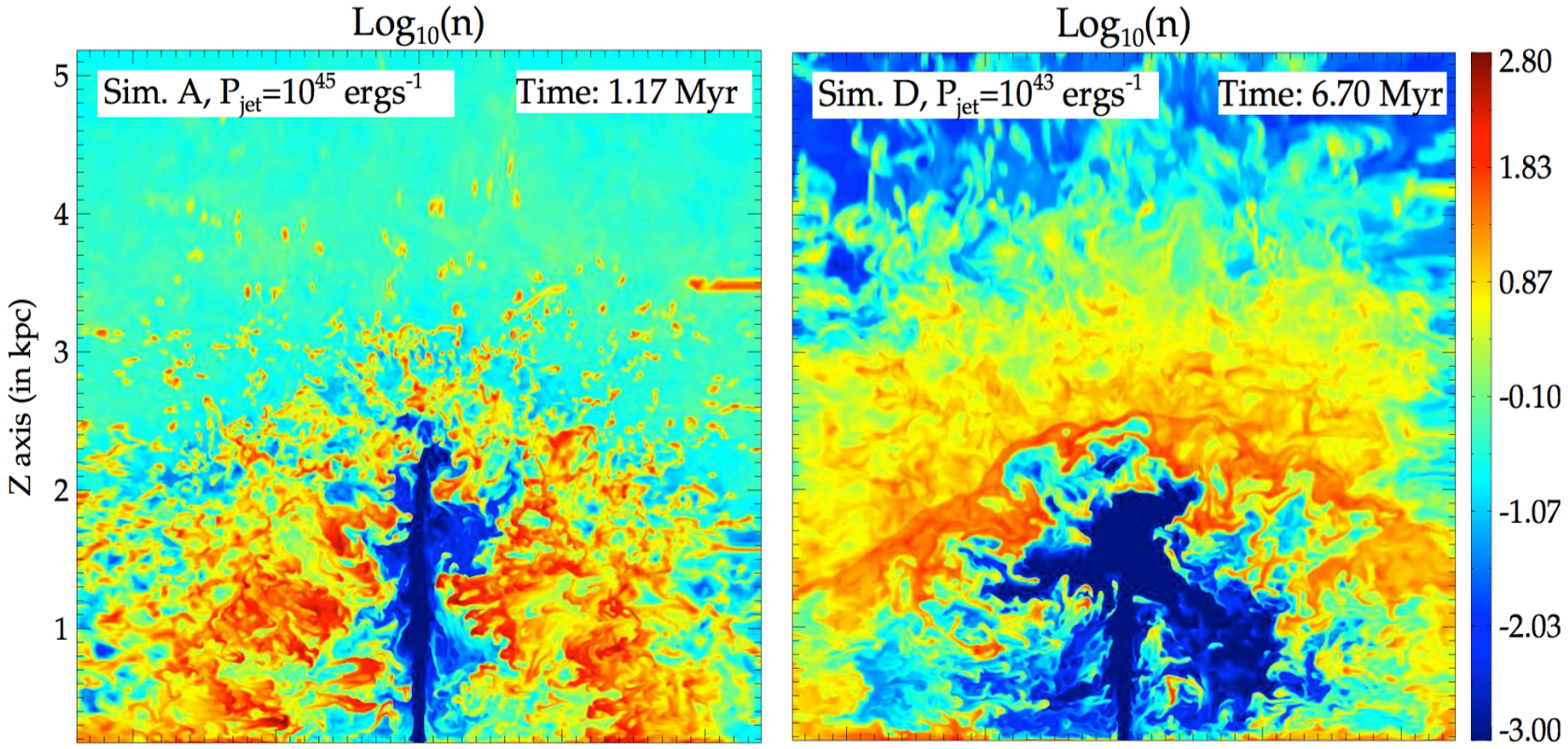
Wiphu Rujopakarn (U. Tokyo)

Community study + science use case collaborators

Radio jet-ISM Feedback



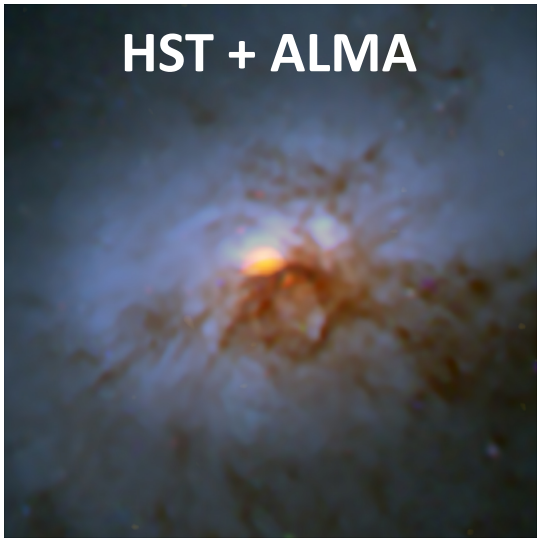
Simulations from Mukherjee et al. 2016

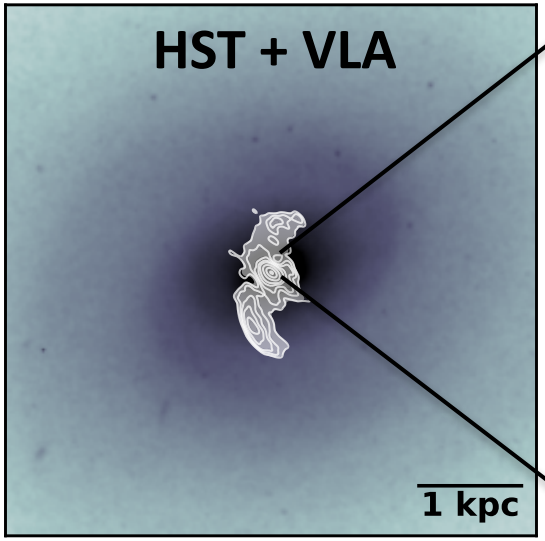
Low-power **jets affect larger ISM volume over a longer time period**

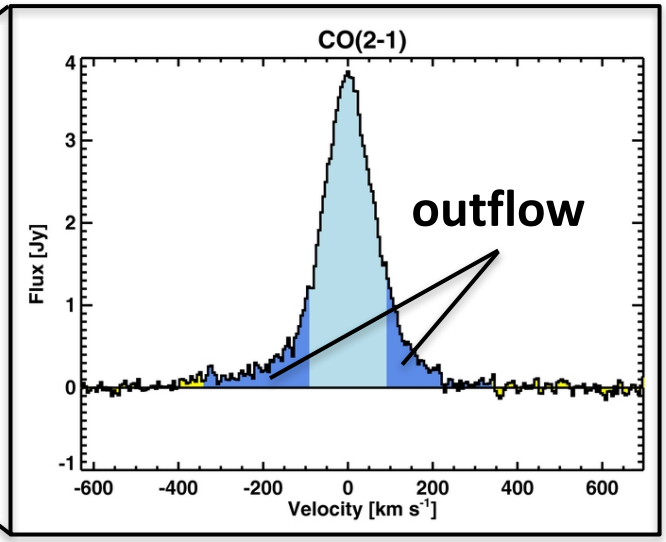
Jet-ISM feedback in lower-power radio AGNs may be important for galaxy evolution

Radio jet-ISM Feedback

NGC 1266







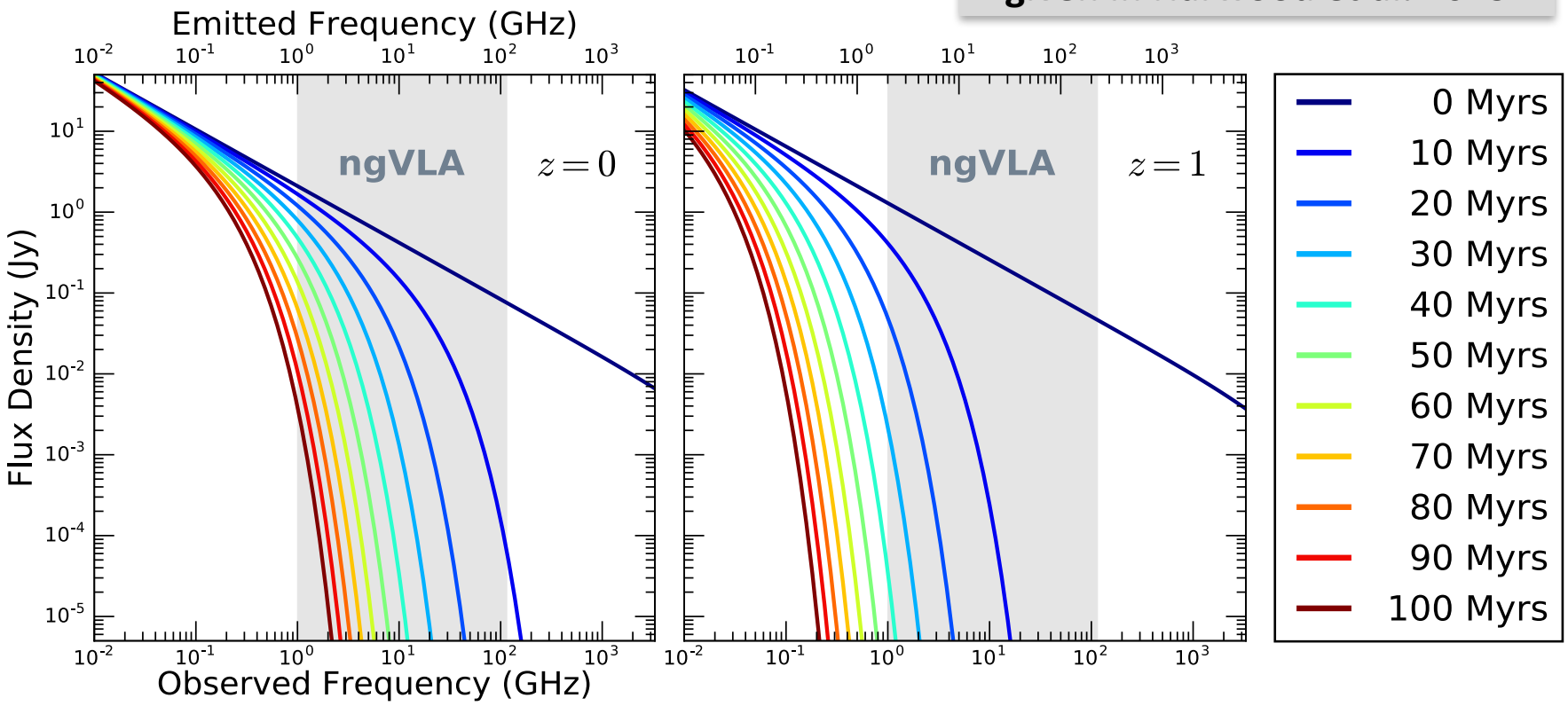
Alatalo et al. 2011, 2014, 2015; Nyland et al. 2013; Davis et al. 2012

Gas-rich galaxy with multi-phase outflow + strong shocks driven by a kpc-scale radio jet

Jet-ISM interactions within galaxies difficult to study – ngVLA would probe this feedback regime!

Radio jet-ISM Feedback

Details on spectral aging models given in Harwood et al. 2013



Spectral age constraints put radio AGNs into broader context of galaxy evolution

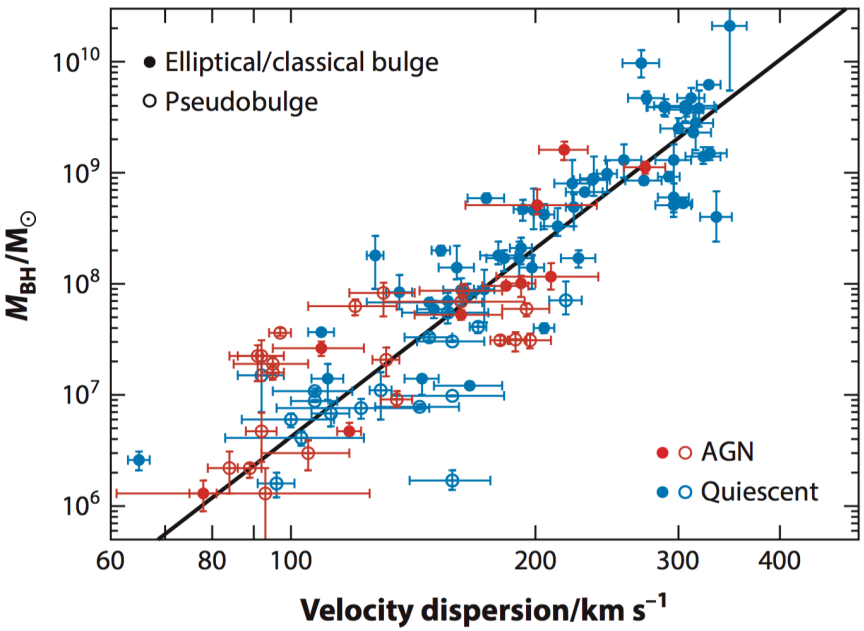
ngVLA will provide radio spectral ages of *young* AGNs engaged in jet-ISM feedback

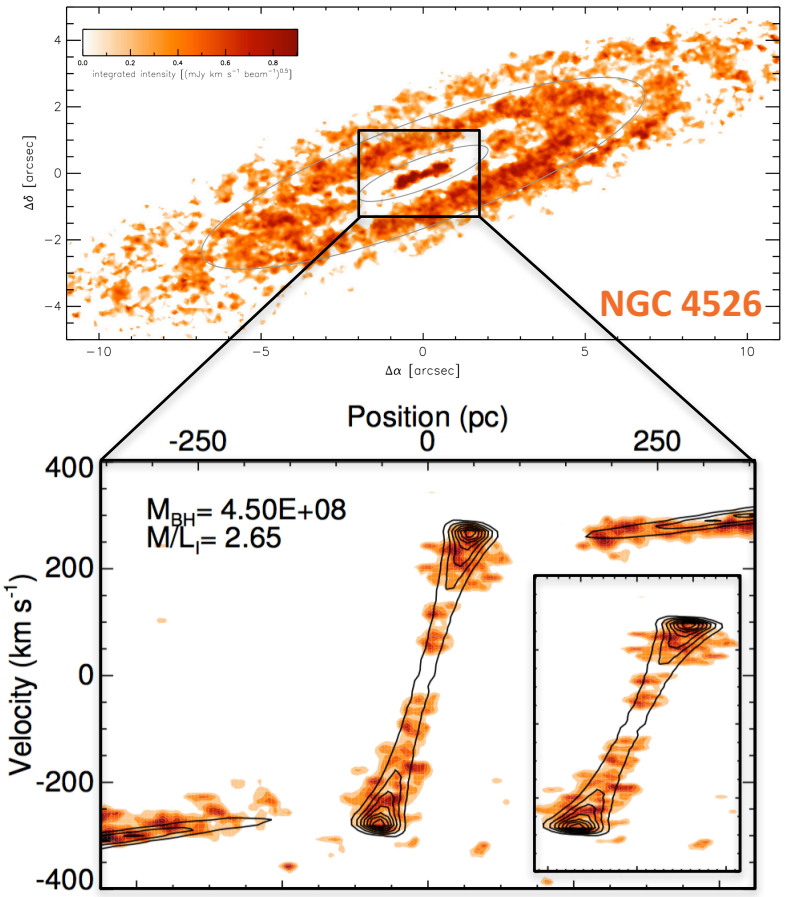
Dynamical MBH Masses

MBH scaling relations for obscured, late-type, bulgeless, and lower-mass galaxies?

MBH masses from CO dynamical modeling

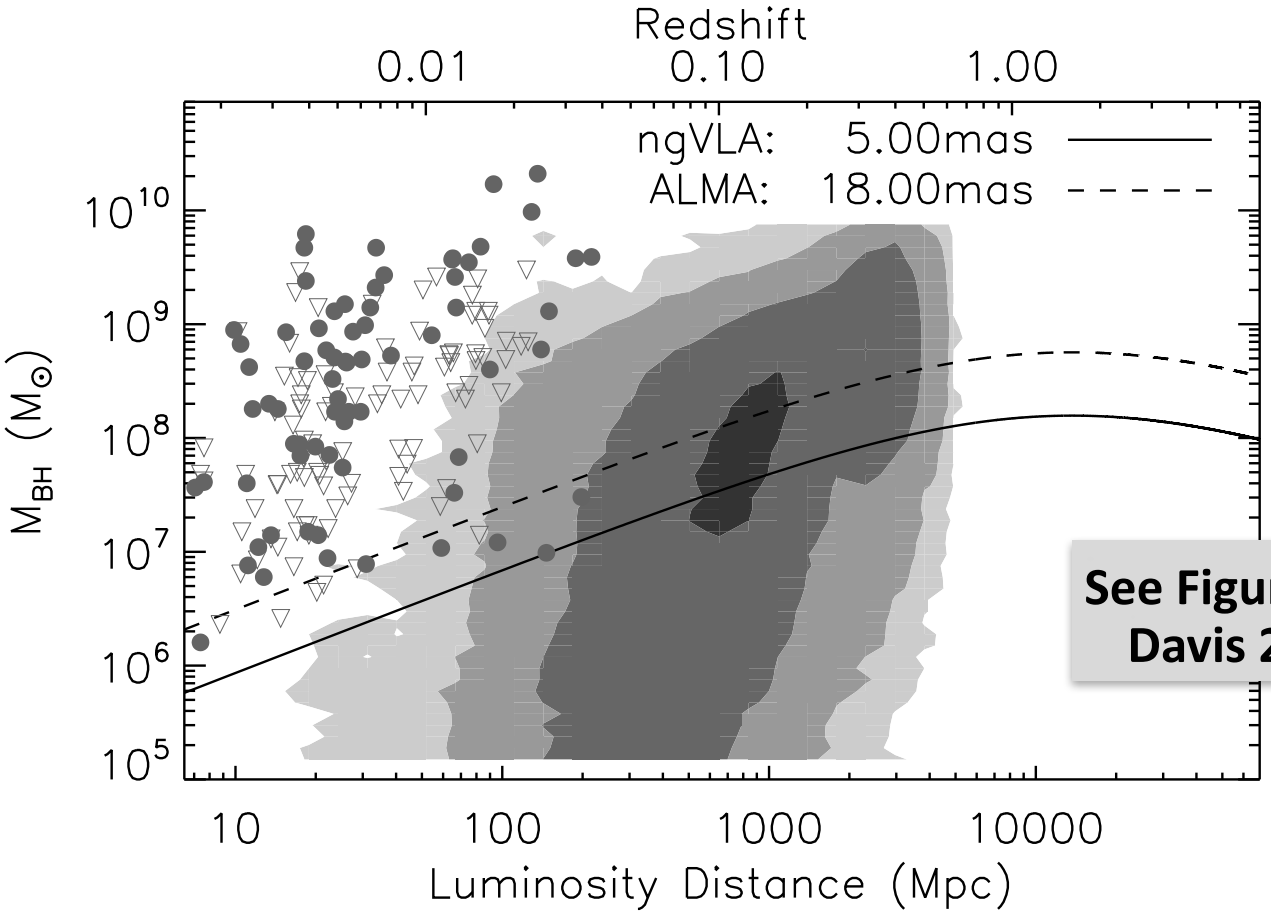
Heckman & Best 2014





Davis et al. 2013; Utomo et al. 2015

Dynamical MBH Masses

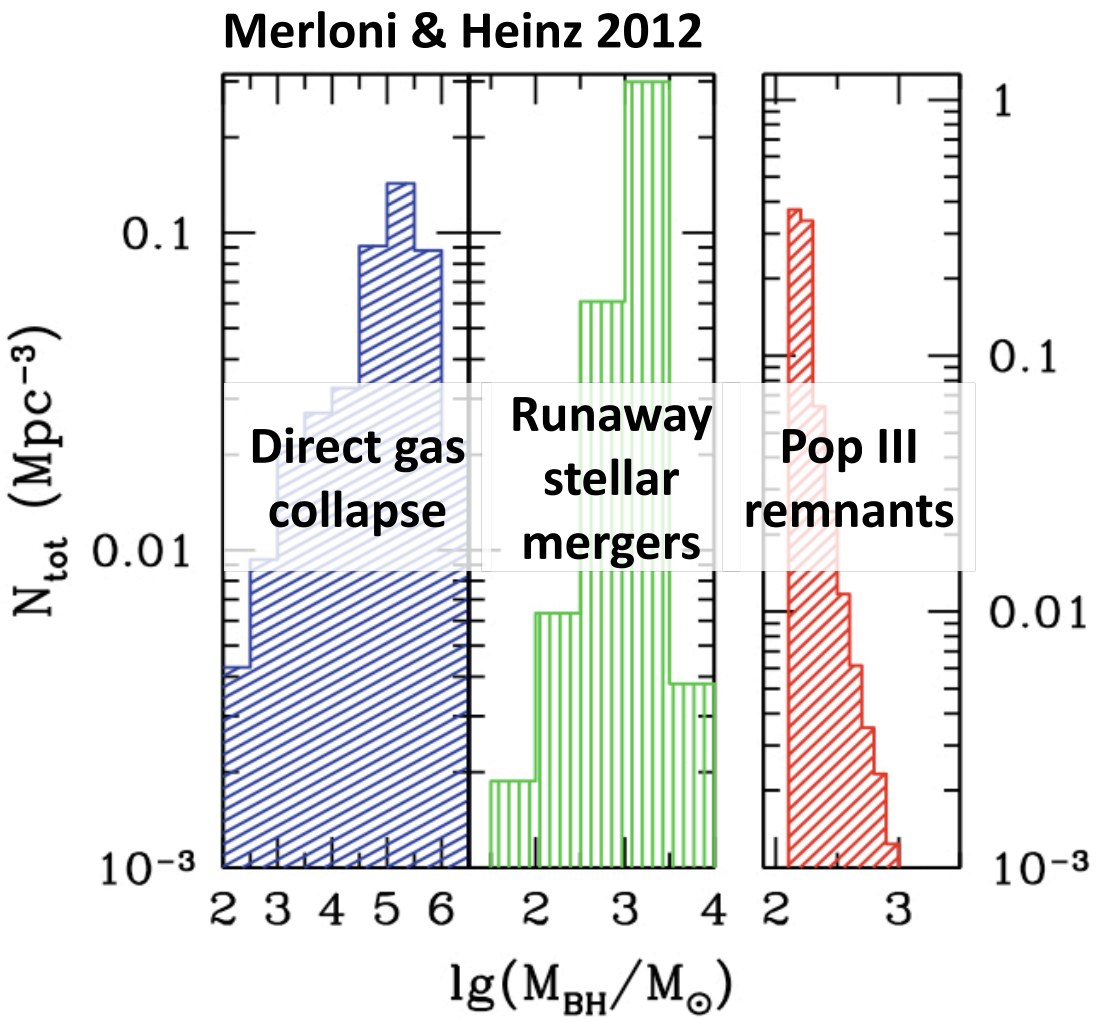


See Figure 7 of Davis 2014

ALMA Band 6 CO(2-1) observations resolve SOI of 243,258 SDSS galaxies

ngVLA will resolve SOI of 440,515 SDSS galaxies with ~500 km baselines

Accreting MBHs in Dwarf Galaxies



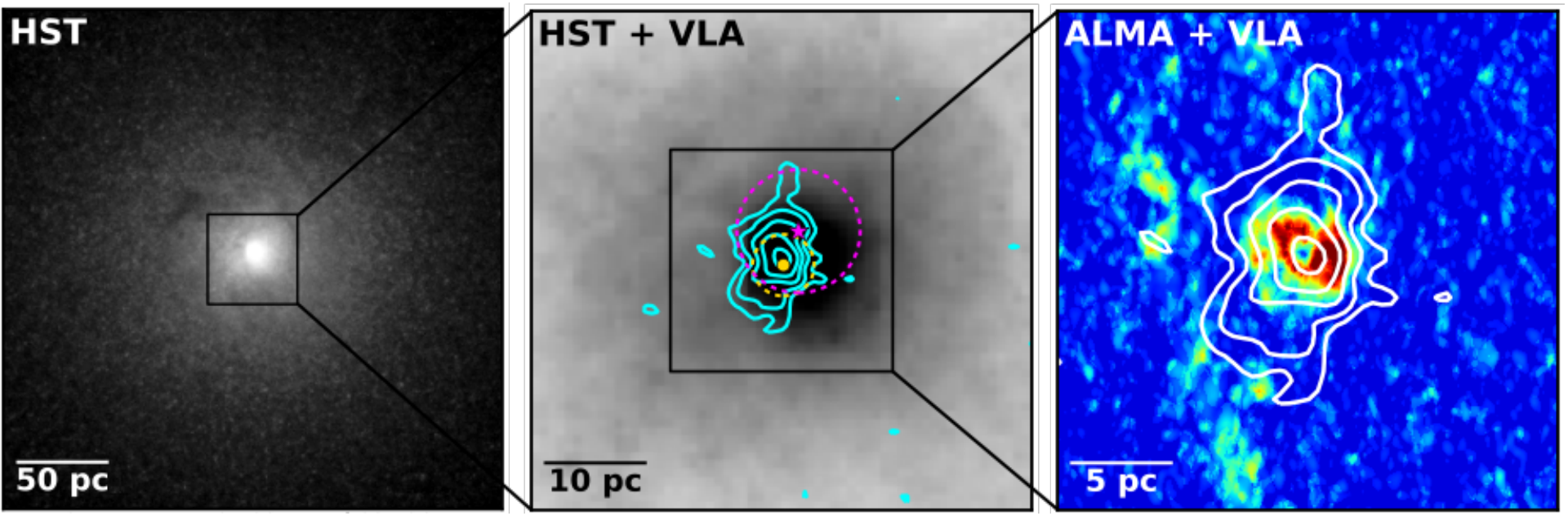
Mass Function of low-mass, low-z MBHs

Distinguish between different formation scenarios of MBH seeds

Accreting MBHs in Dwarf Galaxies

NGC 404

Nyland et al. 2017, submitted to ApJ



JVLA + ALMA can identify MBH seed analogs at low-z in dwarf galaxy nuclei

Current studies limited by sensitivity + resolution – need ngVLA capabilities!

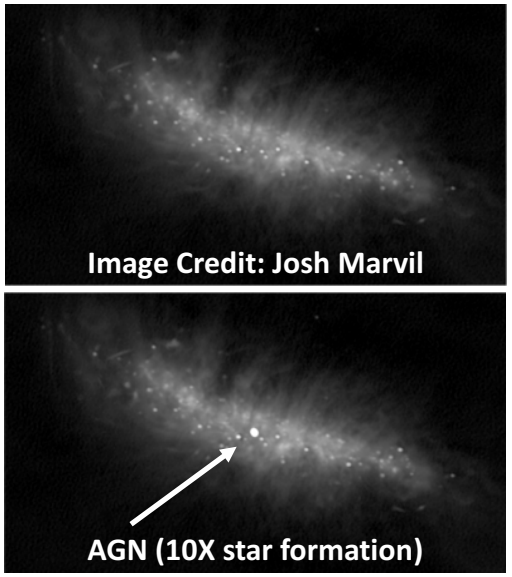
Radio AGNs at high redshift

M82 - JVLA 6 GHz
(A + B + C + D config)

Scale to represent typical main sequence star-forming galaxies at z ~ 1-3

Original

With simulated AGN



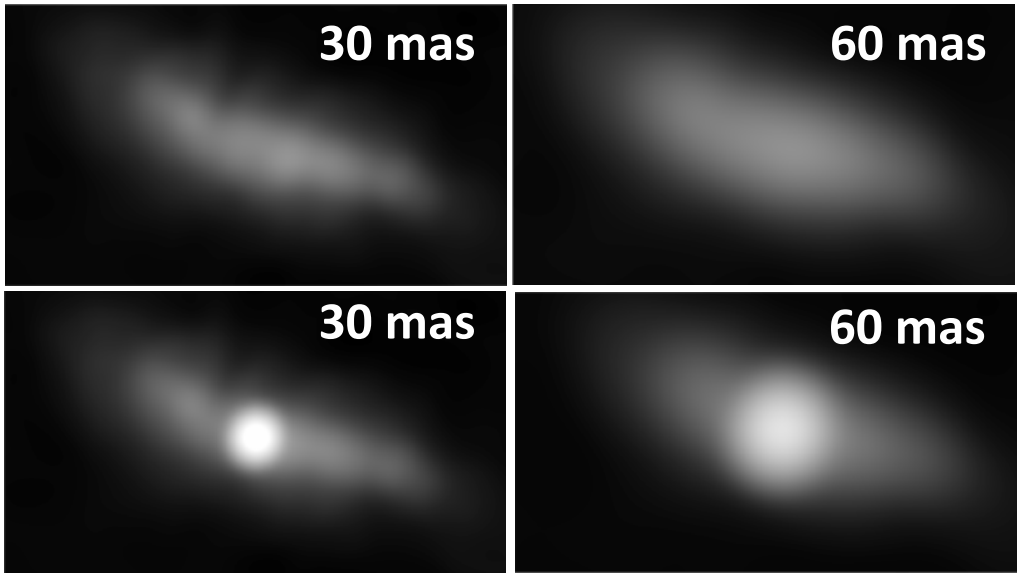


Figure Credit: Wiphu Rujopakarn

High sensitivity and angular resolution of the ngVLA will capture AGN and SF emission in an extinction-free manner at the peak epoch of cosmic assembly

ngVLA Design Requirements

Radio Jet-ISM Feedback	10X JVLA Sensitivity	Multiple Configurations	1.2-116 GHz Freq. Range	Full Stokes	
Dynamical MBH Masses	10X JVLA Sensitivity	>10X JVLA Ang. Res.	B_{max} ≥ 500 km	Phased Array*	VLBI*
Accreting MBHs in Dwarf Galaxies	10X JVLA Sensitivity	>10X JVLA Ang. Res.	1.2-116 GHz Freq. Range		
Radio AGNs at high redshift	10X JVLA Sensitivity	>10X JVLA Ang. Res.	Wide FOV	Survey Speed	

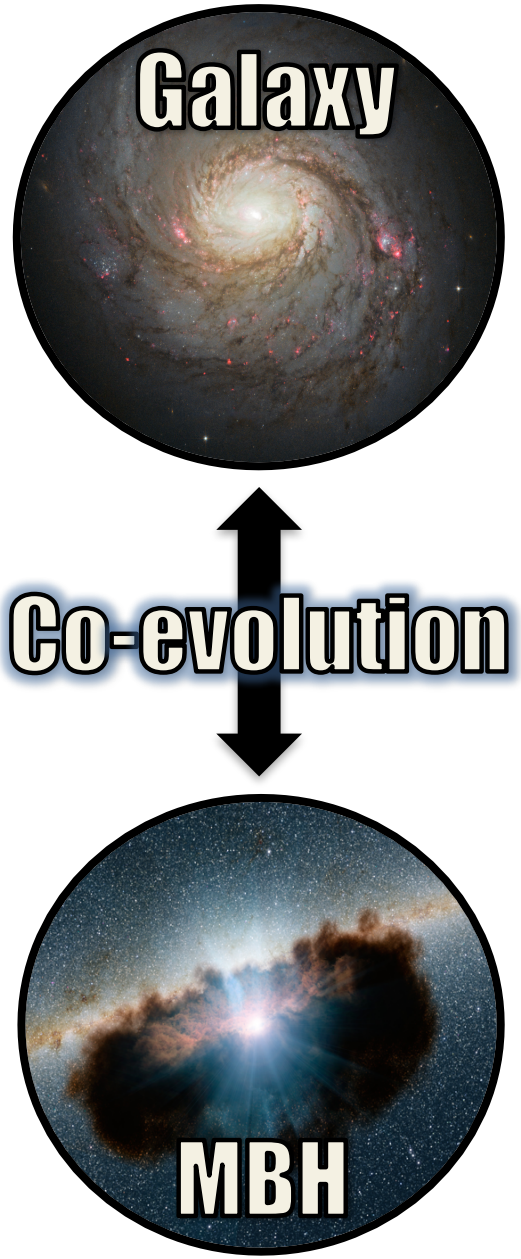
*For megamaser-based dynamical MBH masses only

Take Home Messages

★ ngVLA will revolutionize AGN science by probing MBHs with lower masses, higher redshifts, and MBHs engaged in jet-ISM feedback

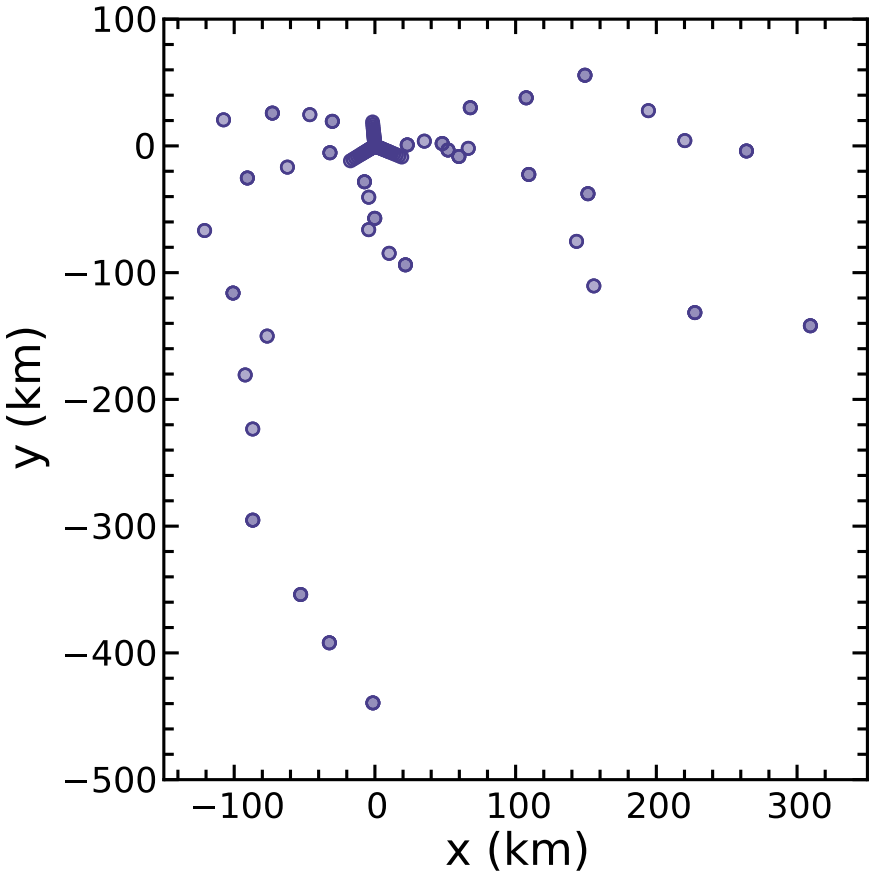
★ Key design requirements:
- 10X higher sensitivity/resolution
- Broad frequency range
- Antenna reconfigurability

★ Stay tuned for final memo on AGN science with the ngVLA with simulations + discussion of synergy with other instruments!

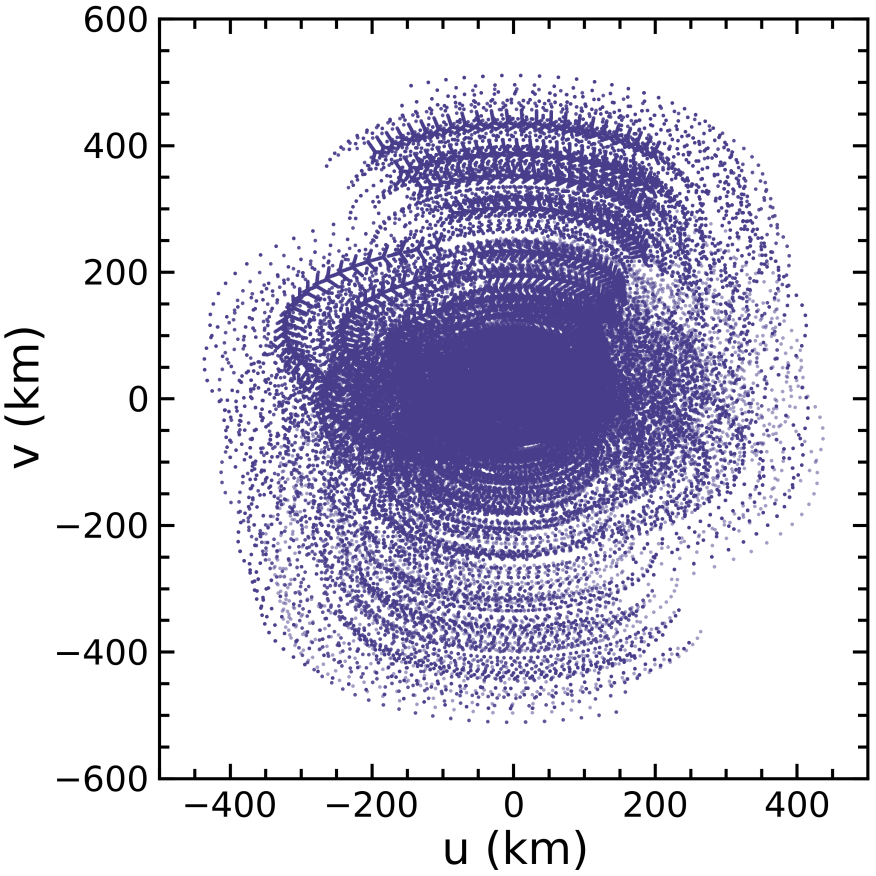



Extra Slides

Simulations



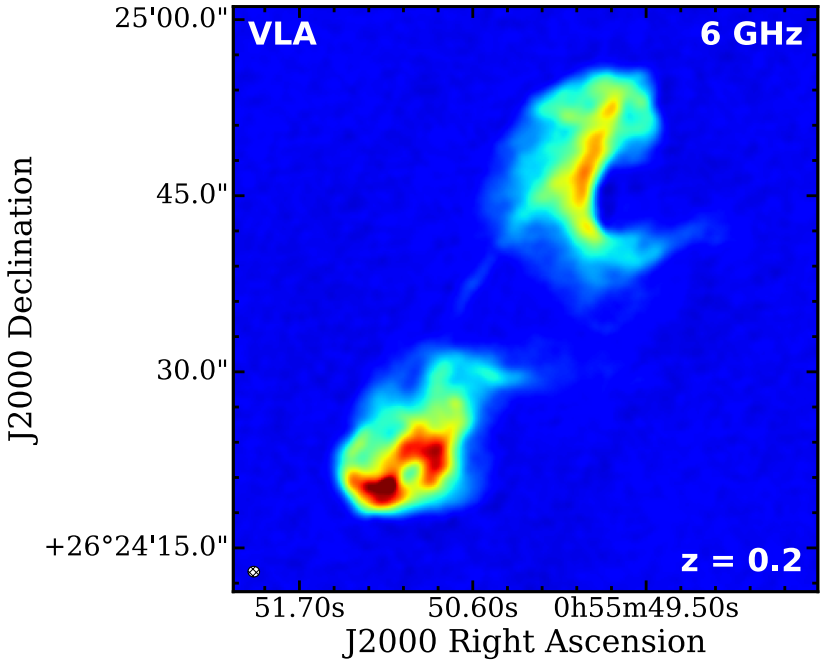
“Southwest” Array



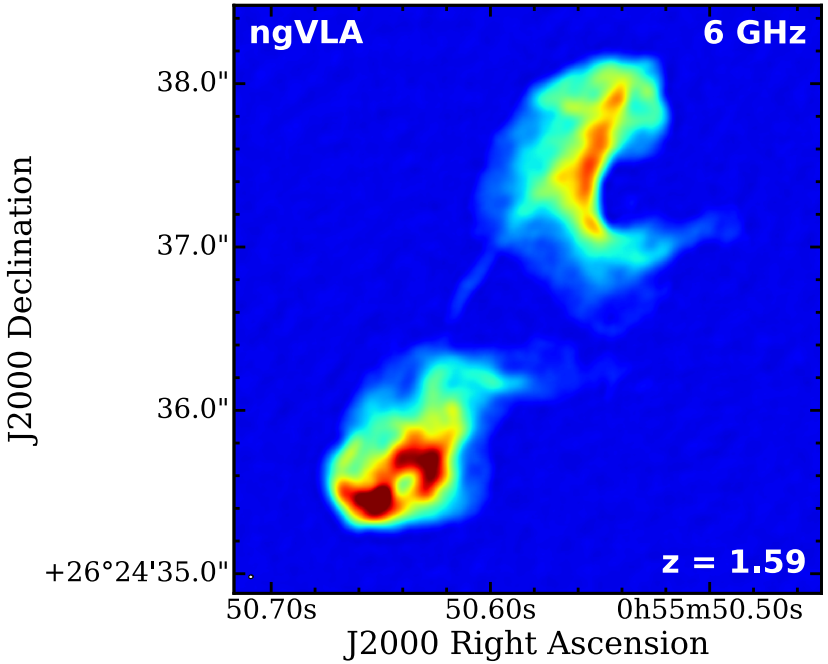
uv-coverage (8 hours)

Simulations Example: 3C28

Original



Simulation



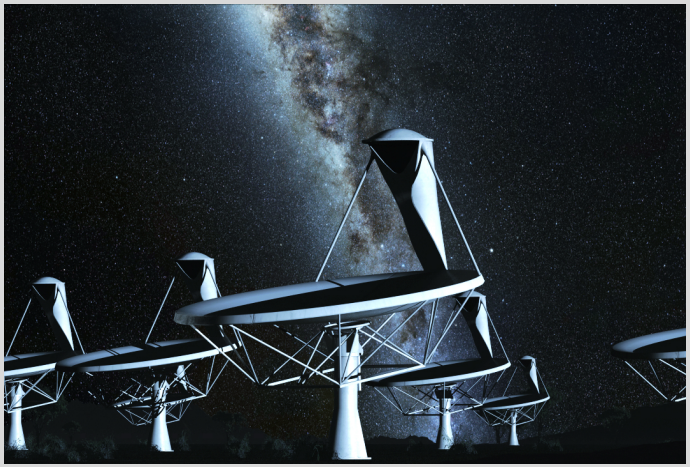
VLA B + C configuration

Southwest Array

ngVLA will be sensitive to AGN structures spanning a wide-range of spatial scales

Further simulations to be presented in memo/white paper (in prep.)

What About the SKA?



Frequency range of SKA → cannot probe spectral ages of *young* radio AGNs directly interacting with ISM

Low-frequency SKA bands will not measure dynamical MBH masses

SKA lacks sufficient resolution for studies of AGNs in dwarf galaxies

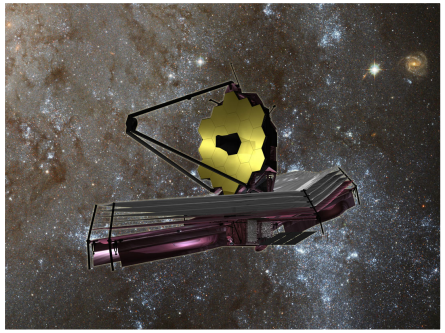
High-z radio AGN studies will be limited by lower SKA resolution

Synergy with other Facilities

ALMA

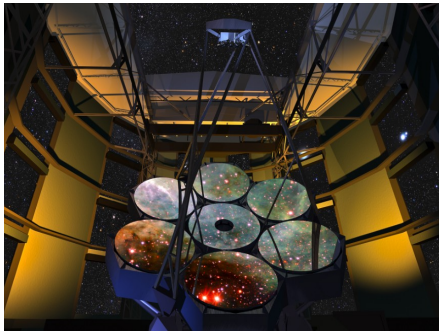
Constraints on ISM conditions in AGN hosts from dense gas tracers

JWST



AGN diagnostics + (high-z) host galaxy properties

Dynamical MBH masses + warm gas conditions and kinematics

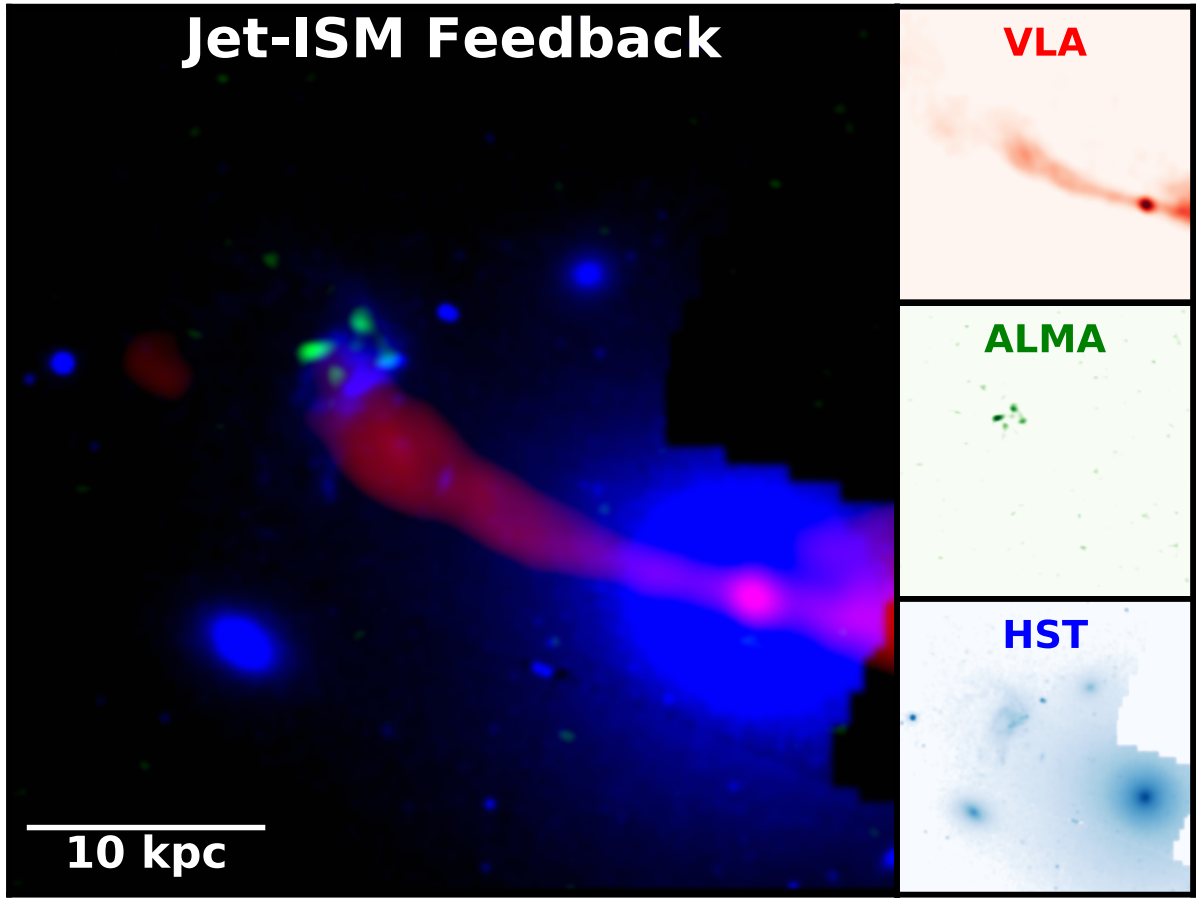


GMT

Lynx

High-resolution X-ray constraints on AGN energetics + hot gas conditions

Radio jet-ISM Feedback

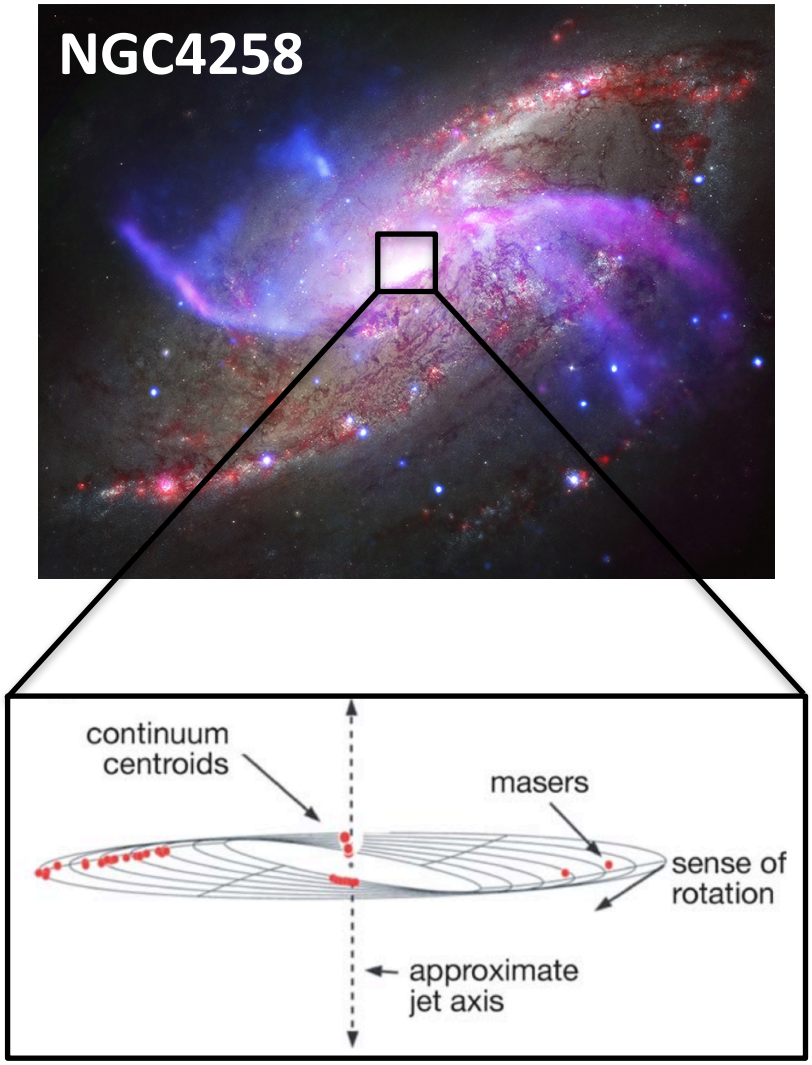


Lacy, Nyland, et al. 2017

Minkowski's Object:
Rare example of a radio jet triggering star formation in a dwarf galaxy

ngVLA continuum + CO studies over the 1.2-116 GHz range will probe *positive* jet feedback

Dynamical MBH Masses

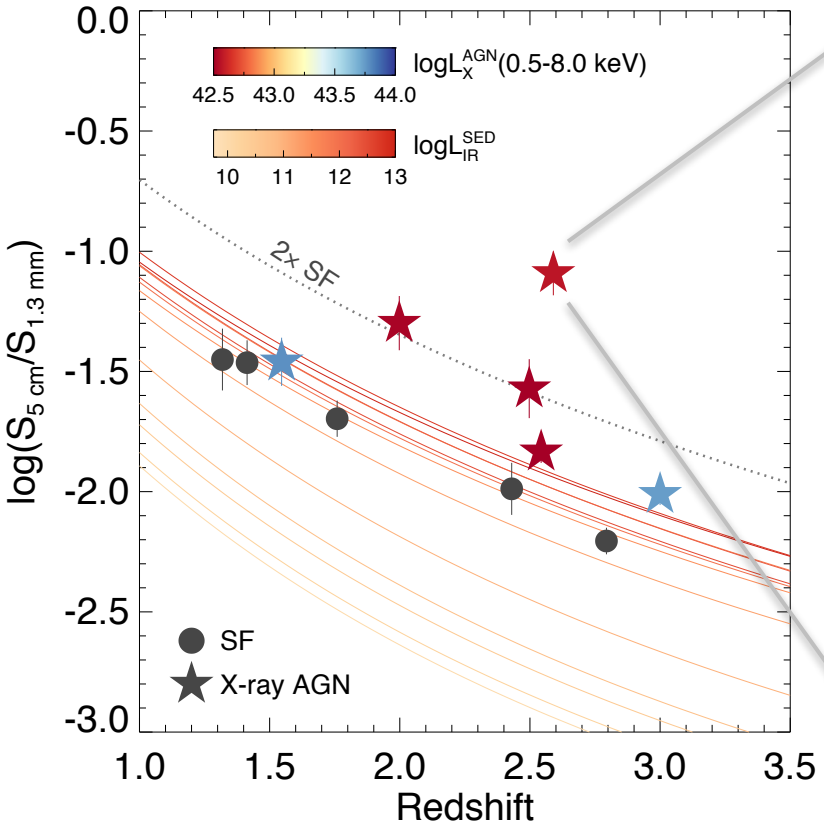


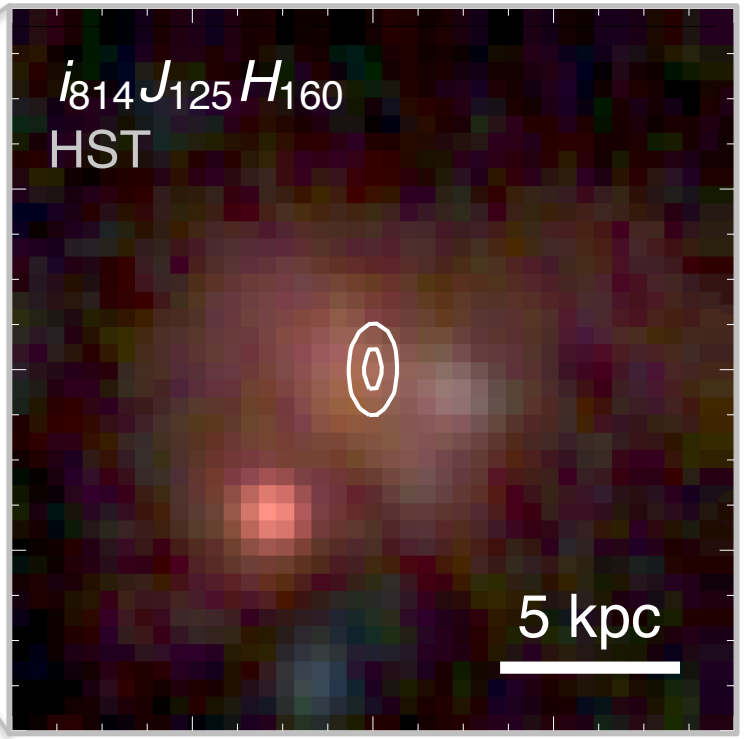
Lo 2005

Accurate MBHs masses from water megamaser disk dynamics

Partner with other facilities (e.g., GBO) to obtain long baselines (θ_{FWHM} ~ 0.3 mas)

Radio AGNs at high redshift





Rujopakarn, Nyland, et al. 2016

Radio excess pinpoints AGNs in z ~ 1-3 galaxies in the HUDF – 177 hrs with JVLA

Need statistical ngVLA study of actively-growing MBHs in "typical" high-z galaxies

Radio AGNs at high redshift

Quasar feedback models predict 10-100 kpc thermal bubbles around quasars

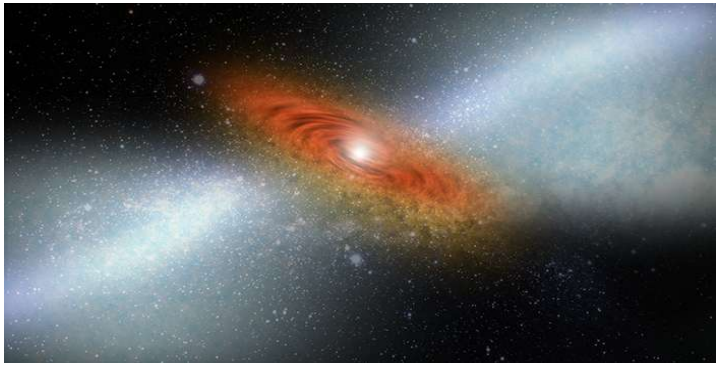
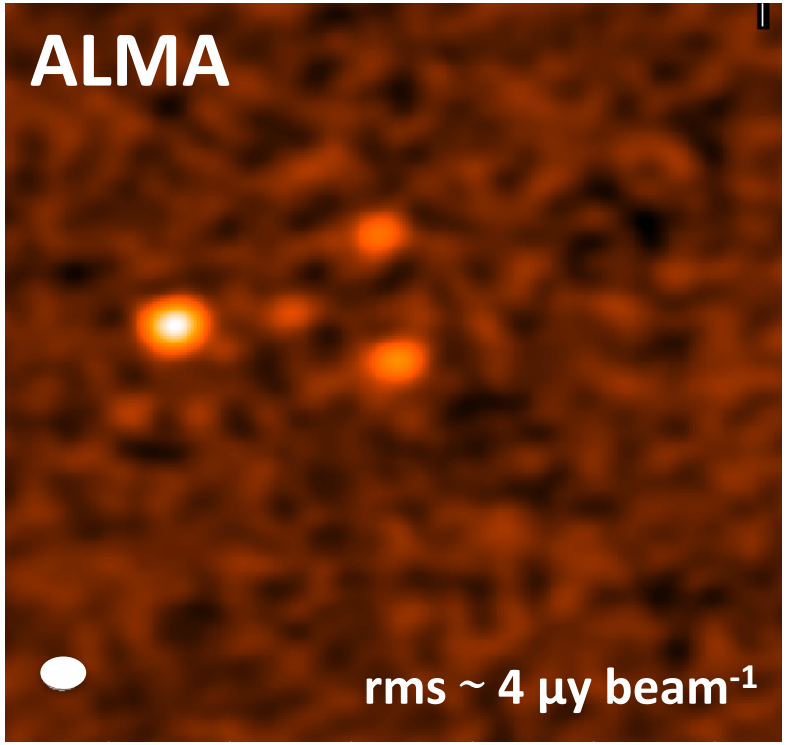


Image credit: Johns Hopkins University



Lacy, Chatterjee, Chakraborty, Nyland, Kimball, Mason, Rocha, Rowe, in prep.

No strong SZ decrement seen in current JVLA/ALMA studies of bright quasars

Improved sensitivity of ngVLA needed to test quasar-mode feedback!

AGN Science in the ngVLA Era

- Radio Jet-ISM Feedback
- Dynamical MBH Masses
- Accreting MBHs in Dwarf Galaxies
- Radio AGNs at high redshift

Co-evolution